April 1, 2004

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP
3815 Old Forest Road
Lynchburg, VA 24501

SUBJECT: DRAFT SAFETY EVALUATION FOR TOPICAL REPORT BAW-10240(P), "INCORPORATION OF M5 PROPERTIES IN FRAMATOME ANP APPROVED METHODS" (TAC NO. MB7553)

Dear Mr. Mallay:

By letter dated October 1, 2002, Framatome ANP submitted Topical Report (TR) BAW-10240(P), "Incorporation of M5 Properties in Framatome ANP Approved Methods," to the staff for review. Enclosed for Framatome ANP's review and comment is a copy of the staff's draft safety evaluation (SE) for the TR.

Pursuant to Section 2.390 of Title 10 of the Code of Federal Regulations (10 CFR), we have determined that the enclosed draft SE does not contain proprietary information. However, we will delay placing the draft SE in the public document room for a period of ten working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects. If you believe that any information in the enclosure is proprietary, please identify such information line-by-line and define the basis pursuant to the criteria of 10 CFR 2.390. After ten working days, the draft SE will be made publicly available and an additional ten working days are provided to you to comment on any factual errors or clarity concerns contained in the SE. The final SE will be issued after making any necessary changes and will be made publicly available. The staff's disposition of your comments on the draft SE will be discussed in the final SE.

To facilitate the staff's review of your comments, please provide a marked-up copy of the draft SE showing proposed changes. Number the lines in the marked-up SE sequentially and provide a summary of the proposed changes.

If you have any questions, please contact Michelle C. Honcharik at 301-415-1774.

Sincerely,

/RA/

Stephen Dembek, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 728

Enclosure: Draft Safety Evaluation

Mr. James F. Mallay
Director, Regulatory Affairs
Framatome ANP
3815 Old Forest Road
Lynchburg, VA 24501

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BAW-10240 (P) “INCORPORATION OF M5 PROPERTIES IN

FRAMATOME ANP APPROVED METHODS”

FRAMATOME ANP

PROJECT NO. 728

1.0 INTRODUCTION

By letter dated October 1, 2002 (Reference 1), Framatome ANP (FANP) requested the NRC's review and approval for referencing in licensing actions Topical Report (TR) BAW-10240(P), "Incorporation of M5 Properties in Framatome ANP Approved Methods." The purpose of BAW-10240(P) is to incorporate the approved M5 cladding material properties into methodology previously reviewed and approved by the NRC for use with Zircaloy-4 cladding. The methods affected, which are numerous and encompass many of FANP's pressurized water reactor (PWR) methodologies, are listed in BAW-10240(P). The methodology described in BAW-10240(P) will be used to support licensing actions for Westinghouse 3- and 4-loop plants and Combustion Engineering (CE) plants for fuel burnups to 62 GWd/MTU.

2.0 REGULATORY EVALUATION

Acceptability of the fuel system design as described in FANP’s TR is based on regulations, General Design Criteria (GDC) of Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR), regulatory guides, industry standards, and on independent calculations and staff judgements with respect to fuel system functions and component selections. The requirements relevant to the fuel system design are as follows:

1. The regulation at 10 CFR 50.46, as it relates to the cooling performance analysis of the emergency core cooling system (ECCS) using an acceptable evaluation model, and establishing acceptance criteria for light water nuclear power reactor ECCS.

2. The regulation at 10 CFR Part 100 as it relates to determining the acceptability of a reactor site based on calculating the exposure to an individual as a result of fission product releases to the environment following a major accident.

3. GDC 10, "Reactor design," as it relates to assuring that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOO).

4. GDC 27, "Combined reactivity control system capability," as it relates to the reactivity control system being designed with appropriate margin, and in conjunction with the ECCS, being capable of controlling reactivity and cooling the core under post-accident conditions.

5. GDC 35, "Quality of reactor coolant pressure boundary," as it relates to providing an ECCS to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented, and (2) clad metal-water reaction is limited to negligible amounts.

The fuel system changes and fuel rod failure mechanisms of Standard Review Plan (SRP) Section 4.2 are specifically addressed in Sections 3.3.1 and 3.3.2 of this safety evaluation (SE), respectively.

3.0 TECHNICAL EVALUATION

BAW-10240(P) describes the incorporation of the NRC-approved M5 material properties (see References 2 and 3) into a set of FANP-approved mechanical analysis, small break loss-of-coolant accident (SBLOCA), and non-loss-of-coolant accident (non-LOCA) methodologies. The mechanical analysis methodology is summarized in Reference 4, the SBLOCA methodology in Reference 5, and the non-LOCA methodologies in References 6, 7, and 8. This set of methodologies will be referred to as FANP Group M methodology to differentiate from other FANP methods which have been approved by the NRC.

For most M5 material properties, an approved model from References 2 or 3 was available, and incorporation of these properties into the methods was straightforward. However, some properties that were needed were either not available in the approved documents, required a range of applicability that extended outside the approved range, or required a new correlation for model-specific usage. These properties include creep, growth, thermal expansion, emissivity, elastic modulus, and rod rupture flow blockage.

Both the approved RODEX2-2A code and the S-RELAP5 code require modifications to integrate the approved M5 cladding material properties into the FANP methodologies. Some M5 material properties were available in a form that was more detailed than the current Zircaloy representation. As a result, some M5 cladding properties have been incorporated using a more detailed representation than that which was previously used for Zircaloy cladding.

No modifications to the base methodology were required for the inclusion of the M5 properties in the RODEX2-2A and S-RELAP5 codes. Modification of some of the approved mechanical criteria was required for consistency with the methodology approvals for M5. These include the clad stress limits and the clad corrosion criteria. M5 is a proprietary variant of a zirconium (Zr) alloy with a nominal 1 percent niobium (Nb) content that has desirable high burnup performance. It provides significant improvements in corrosion, hydrogen pickup, axial growth and diametral creep, relative to Zircaloy.

3.1 Incorporation of M5 Cladding Properties in RODEX2-2A

3.1.1 Summary of Cladding-Related Models in the Fuel Performance Evaluation Model

3.1.1.1 M5 Cladding Creep Correlation and Benchmarking

Cladding creep is dependent on the stress history of the cladding wall, including the internal gas pressure, the coolant pressure, and the fuel cladding mechanical contact forces, as well as the temperature and irradiation histories. The creep model used in RODEX2-2A for M5 cladding is documented on page G-10 of Reference 9 (MTYPE=4 Creep Model). The staff has approved the use of the MTYPE=4 model in RODEX2-2A for SEMIPWR-98 application (Reference 10). This model was already available in RODEX2-2A. Only the constants have been adjusted to represent M5 cladding creep behavior as described in References 2 and 3. The previously defined M5 model for creep was not used in RODEX2-2A, because the previously approved model (Reference 2) was not compatible with RODEX2-2A.

The staff requested additional information from FANP in Reference 11, and asked FANP to provide information about how the previously approved M5 creep model is not compatible with RODEX2.

In response (Reference 12), FANP states creep equations for use with M5 were approved in Reference 2 (page B-3) for application with the TACO3 fuel rod code and in Reference 3 (page 7-6) for use in the COPERNIC fuel rod code. The TACO3 code uses an equation with thermal and irradiation components developed for Zircaloy and modified with an effective creep multiplier for M5. The COPERNIC code uses an equation for M5 with a thermal component with strain hardening and an irradiation component. These equations are both benchmarked to the circumferential strain of the cladding. The RODEX2 equation was developed independently for Zircaloy and was submitted in Reference 13 (page G-9). It is similar to the creep equation used in the COPERNIC code and additionally has a dependence on the anisotropic coefficients of the cladding. The use of anisotropic behavior results in a model which is easier to benchmark for axial elongation. The RODEX2 model uses measured M5 anisotropic coefficients, and like the other equations is benchmarked to the irradiated clad tangential strain. The RODEX2 equation was utilized primarily because it required no change to the RODEX2 coding. Based on FANP’s explanation above, the staff finds this response acceptable.

Data from M5 clad fuel rods used for three cycles were used to benchmark the radial cladding creep calculated by RODEX2-2A. Each of the rods have identical design parameters. The rods were irradiated and the radial creep was measured at 12 axial locations for each of the rods in Cycles 1 and 2, and at 10 axial locations for each of the rods in Cycle 3.

The RODEX2-2A M5 creep parameters were established by regression analyses of the comparison of measured to calculated results for these rods for various creep coefficients. Regression analyses of the predicted one- and two-cycle creep versus the measured creep were used to select the parameters that produced results with a regression coefficient of 1.0. The Cycle 3 rod diameter measurement data were not included in regression analyses, because the rod-diameter measurement results indicate that pellet-cladding interaction (PCI) occurred during the third cycle of irradiation.

The results of the comparison between the calculated and measured creep values as a function of local burnup demonstrate that the RODEX2-2A creep prediction gives acceptable agreement with the measured data (Figure 4.5 of Reference 1). Based on these results, the staff finds the M5 cladding creep correlation acceptable.

3.1.1.2 M5 Cladding Free Growth Correlation and Benchmarking

The M5 irradiation-induced cladding free growth contributes to the total fuel rod growth calculation in RODEX2-2A. Cladding free growth for M5 was not reported separately from total fuel rod growth in previously approved FANP submittals. For incorporation into RODEX2-2A, however, this model is described.

The irradiation-induced free growth of M5 is one part of the fuel rod elongation with the remainder coming from axial creep. The model, which is implemented in RODEX2-2A for irradiation-induced cladding free growth of M5, is a fraction of the existing Zircaloy-4 growth model. It was determined by benchmarking the overall rod elongation, including creep, against the irradiated M5 rod growth data.

The M5 rod growth benchmarking indicated that the M5 stress-free irradiation growth coefficient differs from the one for Zircaloy. Also, the application of friction force after PCI as described in the RODEX2-2A Equation G.7 of XN-NF-81-58(P)(A) is needed. The friction coefficient and the stress-free irradiation-induced rod growth correlation for M5 cladding were determined through benchmarking to the rod growth results.

Post-irradiation measured M5 clad data were used for RODEX2-2A M5 rod growth validation. The M5 rod growth validation contains two parts. The first part is for the M5 rods that have had creep measured. The number of growth data points for these rods is limited, but rod-specific power histories are available. The second part has a large number of M5 growth data points available, but no rod-specific power histories. Thus, typical 17x17 power histories were used for the validation.

The results of the two parts demonstrate that the M5 rod growth models produce good growth predictions (Figures 4.6 and 4.7 of Reference 1). Based on these results, the staff finds the M5 growth correlation in RODEX2-2A acceptable.

3.1.1.3 M5 Cladding Thermal Conductivity

The thermal conductivity (W/m-K) of M5 cladding is taken from the NRC-approved Reference 3 (Equation 10-30).

3.1.1.4 M5 Cladding Zr Oxide Thermal Conductivity

The Zirconia thermal conductivity values (W/m-K) on M5 cladding is taken from the NRC-approved Reference 3 (Equations 10-31 through 10-33).

3.1.1.5 M5 Cladding Specific Heat

Specific heat is not used in the RODEX2-2A code. RODEX2-2A calculations assume quasi-steady thermal conditions for each burnup interval so specific heat is not required.

3.1.1.6 M5 Cladding Density

Cladding density is not used in the RODEX2-2A code. Cladding density would be multiplied by specific heat to provide volumetric heat capacity. However, since RODEX2-2A assumes quasi-steady state heat transfer, volumetric heat capacity is not required.

3.1.1.7 M5 Cladding Thermal Expansion

The integral coefficient of thermal expansion is based on the model approved by the NRC in Reference 2 (Appendix I and Section K-2.4). The a and b phase expansion rates were approved in Reference 2. Expansion rate coefficients for the current model follow those presented in References 2 and 3, except that the a phase expansion coefficient in the axial direction has been rounded down slightly to provide one value for the different components of an all M5 fuel assembly.

The safety evaluation (SE) for Reference 2 states that the transition range in the approved model begins at a temperature that is about 60°C too low. In response to this observation, the transition region has been modified and the model now begins at a temperature that is 50°C above the previous model temperature. These values are discussed in Section 4.1.7 of Reference 1.

The staff requested additional information from FANP in Reference 11, and asked FANP to provide justification for rounding the alpha phase expansion coefficient in the axial direction down.

In accordance with Reference 12, FANP explained the value being adjusted is a multiplier in the axial thermal expansion formula for the alpha phase range. FANP uses a corporate-wide materials property reference for M5. Although this value is slightly lower than the multiplier, the impact of the change is minimal. The stated uncertainty in the coefficient of thermal expansion in the alpha phase is well within the uncertainty in the correlation.

Based on the minimal impact of the change and the stated uncertainty in the coefficient of thermal expansion in the alpha phase is well within the uncertainty in the correlation, the staff finds the M5 cladding thermal expansion calculations acceptable.

3.1.1.8 M5 Cladding Elastic Modulus

The Young's modulus for cladding elastic deformation is taken from the NRC-approved Reference 3 (Equation 10-54). The equation is valid for a specific temperature range with an associated uncertainty.

3.1.1.9 M5 Cladding Poisson's Ratio

Poisson's ratio is taken from the NRC-approved Reference 2 (page I-75).

3.1.1.10 M5 Cladding Emissivity

Emissivity is used in the RODEX2-2A fuel model in calculating the small radiation component of the internal gap conductance. The emissivity correlation approved in Reference 2 (page I-73) is for high temperature oxidized applications. RODEX2-2A calculations are typically performed at cladding temperatures below 400°C. At low temperatures and low oxidation, the emissivity of Zr alloys is smaller. The data produced by Murphy and Havelock (Reference 14) for Zr alloy with a nominal 2.5 percent Nb content between 100°C and 400°C can be fitted by a degree-2 polynomial (Figure 4.2 of Reference 1) to develop a low temperature, low oxidation correlation. To provide a smooth transition between the high temperature and low temperature correlations, the range of the low temperature correlation is extended upward and the range of the high temperature correlation is extended downward to the crossover point of the two correlations. The combined correlation over the entire temperature range can be seen in Figure 4.3 of Reference 1.

The staff requested additional information from FANP (Reference 11) to provide additional information and justification on how the transition region was developed since it is not a smooth transition.

Based on information provided in FANP's response (Reference 12), specifically the more accurate model and the insignificant effect the emissivity value has on gap heat transfer used for the cladding in the transition range, the staff finds the response acceptable.

3.1.1.11 M5 Cladding Corrosion

The pre- and post-transition M5 cladding corrosion models presented in the NRC-approved Reference 3 (pages 8-7 through 8-9 and Equations 8-14 and 8-16) are implemented in RODEX2-2A.

3.1.1.12 M5 Cladding Hydrogen Pickup

The M5 cladding relationship for hydrogen content presented in the NRC-approved Reference 3 (page 8-15 and Equation 8.37) is implemented in RODEX2-2A.

3.1.1.13 High Temperature M5/Steam Reaction Kinetics

The RODEX2-2A calculations are performed at normal reactor operating conditions. The temperature of the cladding during normal operating conditions is not high enough for significant metal-water reaction to take place. Therefore, only cladding corrosion models are used to determine cladding oxidation in the RODEX2-2A code. A separate high-temperature M5/steam reaction kinetics model is not required.

3.1.1.14 M5 Cladding Swelling and Rupture/Blockage

The RODEX2-2A code is used to calculate burnup-dependent fuel behavior at normal reactor operating conditions. Under these conditions, swelling and rupture/blockage will not occur and, therefore, no swelling and rupture/blockage model is implemented in the RODEX2-2A code.

3.2 Incorporation of M5 Properties in S-RELAP5

3.2.1 Summary of Cladding-Related Models in the Thermal-Hydraulic Performance Evaluation Model

Currently, S-RELAP5 is approved for use in SBLOCA and SRP Chapter 15 non-LOCA calculations (References 5 and 6). For non-LOCA calculations, properties related to cladding and fuel-clad gap are input to the code, and the S-RELAP5 internal cladding models are not used. Therefore, the SBLOCA methodology is currently the only approved methodology that directly uses the cladding models in the S-RELAP5 code.

3.2.1.1 M5 Cladding Creep Correlation

Cladding creep is a burnup-dependent parameter. The duration of an S-RELAP5 SBLOCA calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding creep is not calculated in the S-RELAP5 code.

3.2.1.2 M5 Cladding Free Growth Correlation

Cladding irradiation-induced free growth is a burnup-dependent parameter. The duration of an S-RELAP5 SBLOCA calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding free growth is not calculated in the S-RELAP5 code.

3.2.1.3 M5 Cladding Thermal Conductivity

The thermal conductivity (W/m-K) of M5 cladding is taken from the NRC-approved Reference 3 (Equation 10-30).

3.2.1.4 M5 Cladding Oxide Thermal Conductivity

The thermal conductivity values (W/m-K) on M5 cladding is taken from the NRC-approved Reference 3 (Equations 10-31 through 10-33).

3.2.1.5 M5 Cladding Specific Heat

The specific heat (J/kg-K) values for M5 cladding are approved in Reference 2 (page I-72).

3.2.1.6 M5 Cladding Density

The density of M5 cladding is taken from the NRC-approved Reference 2 (page I-70).

3.2.1.7 M5 Cladding Thermal Expansion

The thermal expansion model for M5 cladding described in Section 3.1.1.7 of this SE is also used in the S-RELAP5 code. For S-RELAP5, models for the entire temperature range to 1400°C are incorporated.

3.2.1.8 M5 Cladding Elastic Modulus

The approved elastic modulus model for M5 cladding described in Section 3.1.1.8 of this SE is also used in the S-RELAP5 code. In S-RELAP5 applications, however, Equation 4.9 of Reference 1 is assumed applicable to all temperatures of interest. Table 5.1 of Reference 1, compares the elastic modulus values of M5 from Equation 4.9 and those for Zircaloy used in S-RELAP5/RODEX3A (Equation 7.127 of Reference 15). The RODEX3A formulation is a more recent formulation from MATPRO-11 and provides a more detailed representation than that used for Zircaloy-4 in the SBLOCA methodology. FANP stated that the extension of Equation 4.9 to the entire LOCA temperature range is within the standard error of the Zircaloy correlation and therefore, the range extension is acceptable.

The staff requested additional information from FANP in Reference 11 and asked FANP to provide justification that Equation 4.9 is assumed applicable to all temperatures of interest. FANP was also asked to define the temperature range of interest.

In accordance with Reference 12, FANP explained the temperature range of interest, discussed in Section 5.1.8 of Reference 1, extends from post-accident cold conditions (around 300 K) to the upper cladding temperature allowed for LOCA calculations (around 1500 K). Table 5.1 of Reference 1, provides a comparison between the M5 Young's Modulus correlation (Equation 4.9), and the Zircaloy Young's Modulus correlation from MATPRO-11 for temperatures ranging from 300 K to 1600 K. Over this range, the two correlations are well-behaved and trend together. Either could easily be approximated as a simple linear function of temperature. The extension of the correlation to higher temperatures for accident analysis is based on general observations of data for various similar alloys, the close relationship of the M5 modulus and the Zircaloy modulus in the low temperature range, and the low importance of elastic expansion to accident evaluations in the high temperature range. The extension of the correlation was considered during the review of the M5 TR (Appendix K, Section K.3 of Reference 2), with the result that the extension of the correlation to temperatures up to 1500 K was approved.

Based on: (1) the close relationship of the M5 modulus and the Zircaloy modulus in the low temperature range, (2) the low importance of elastic expansion to accident evaluations in high temperature range, and (3) the extension was considered during the review of the M5 TR in Reference 2 with the result that the extension of the correlation to temperatures up to 1500 K was approved, the staff finds the M5 cladding elastic modulus acceptable.

3.2.1.9 M5 Cladding Poisson's Ratio

Poisson's ratio is taken from the NRC-approved Reference 2 (page I-75).

3.2.1.10 M5 Cladding Emissivity

Emissivity is used in the RODEX2-2A fuel model in S-RELAP5 to calculate the radiation component of the internal gap conductance. For this purpose, S-RELAP5 uses the same values as described in Section 3.1.1.10 of this SE. For S-RELAP5, the models for the entire temperature range are incorporated. S-RELAP5 also calculates rod external radiation to the coolant. For this purpose, S-RELAP5 uses the emissivity defined in Section 4.8 of Reference 15. The value that is used is the same for both Zircaloy and M5 cladding. This value is based on the analysis of core cooling for boiling water reactor rod bundles. FANP stated that using a conservative external emissivity maintains consistency with the treatment of Zircaloy cladding.

Based on the insignificance of the emissivity value, the staff agrees that the same value can be used for both Zircaloy and M5 cladding. The staff finds the M5 cladding emissivity used in S-RELAP5 acceptable.

3.2.1.11 M5 Cladding Corrosion

Low temperature cladding corrosion is not calculated in S-RELAP5. Section 3.2.1.13 of this SE describes the high temperature M5/steam reaction kinetics model used in S-RELAP5.

3.2.1.12 M5 Cladding Hydrogen Pickup

Cladding hydrogen pickup is not calculated in S-RELAP5. Since the criteria for SBLOCA do not set limits on hydrogen pickup but only on cladding oxidation, the high temperature M5/steam reaction kinetics model only considers oxidation and not hydrogen pickup.

3.2.1.13 High Temperature M5/Steam Reaction Kinetics

Metal-water reaction kinetics in S-RELAP5 for SBLOCA is calculated using the Baker-Just model (Reference 16) as described in Section 12.10 of Reference 15. The same method is used for both Zircaloy and M5 cladding. Baker-Just was approved for use with M5 in Reference 2.

3.2.1.14 M5 Cladding Swelling and Rupture/Blockage

3.2.1.14.1 *M5 Cladding Radial Ballooning and Rupture Deformations*

The FANP M5 cladding ballooning and rupture model is used to compute the radial displacement due to cladding ballooning and rupture (Drcr) at each axial elevation as a function of the hoop stress (s, in kpsi), the average cladding temperature, and the dimension-less cladding heat-up rate (Hc). FANP stated that cladding ballooning and/or rupture only occurs when the cladding temperatures are high and the inside rod pressure is greater than the pressure in the coolant channel. The hoop stress is given by the thin shell formula as described in Equation 12.26 of Reference 16. The cladding heat-up rate is based on the average cladding temperature, which is given by Equation 12.27 of Reference 15.

3.2.1.14.2 *Channel Flow Area and Flow Evaluations*

Before the rupture of the fuel rod, the area of the channel around the fuel rod is given by the relationship in Equation 12.71 of Reference 15. Following fuel rod rupture, the Exxon Nuclear Company WREM II-based blockage model (Reference 17) is used. The model diverts flow from the hot assembly to neighboring assemblies in the blockage plane, and returns flow above the blockage region. The blockage region accounts for rupture at different axial elevations for fuel rods within the assembly. To make the blockage model and the 10 CFR Part 50 Appendix K rupture node length requirement consistent, the region in the vicinity of the rupture is modeled as four axial regions. The 10 CFR Part 50 Appendix K requirement is that inside oxidation must occur in a node which is 3 inches or less in length after cladding rupture. FANP stated the method proposed for M5 cladding is the same method currently approved for use with Zircaloy cladding (Reference 15).

For M5 cladding the average assembly blockage fractions are obtained by linear interpolation of the assembly blockage values in Table 5.4 (Reference 2, the blockage function is plotted on pages K-33 and K-34), which is plotted in Figure 5.3 of Reference 1. The presented blockage fractions were derived for Mark-B 15x15 PWR fuel and were approved for use with Mark-B 15x15 and Mark-BW 17x17 PWR fuel types with M5 cladding in Reference 2. FANP stated the cross-sectional dimensions and lattice structure of the high thermal performance (HTP) 15x15 and 17x17 PWR fuel designs are very similar to those for Mark-B 15x15 and Mark-BW 17x17 PWR fuel designs, respectively. In terms of assembly blockage fraction, FANP stated the values for the HTP 14x14 PWR fuel design differ by only a few percent from those for the Mark-B 15x15 fuel design and is within the accuracy of the data and technique used to derive the blockage values as described in Reference 2. Therefore, FANP concludes the M5 blockage model approved for use with Mark-B 15x15 and Mark-BW 17x17 PWR fuel in Reference 2 will be used for HTP 14x14, HTP 15x15, and HTP 17x17 PWR fuel designs with M5 cladding.

The rupture node assembly average blockage fraction is used to adjust the unblocked flows in the blockage region and downstream of the blockage. These flows are used in the computation of heat transfer coefficients. Table 5.5 of Reference 1 gives the flow as a fraction of the unblocked flow and distance from the center of the rupture node for assembly average blockage fractions of 20 percent and 30 percent. The flow fractions are assumed linear and are defined by the 20 percent and 30 percent blocked values in Table 5.5. FANP noted that the application of the blockage fraction is the same as the model approved for use with Zircaloy cladding in Reference 15.

The staff agrees that the M5 blockage model approved for use with Mark-B 15x15 and Mark-BW 17x17 PWR fuel in Reference 2 can be used for HTP 14x14, HTP 15x15, and HTP 17x17 PWR fuel designs with M5 cladding due to the fuel design similarities.

3.3 PWR Mechanical Analysis Methodology

The description of the incorporation of M5 in the Group M PWR Mechanical Analysis Methodology that follows, is organized in accordance with the SRP Section 4.2 (Reference 18).

3.3.1 Fuel System Damage

3.3.1.1 Stress

The design basis for fuel component stresses in accordance with the approved methodology of Reference 4, specifies that the fuel system will not be damaged due to excessive stresses. Conservative limits are derived from the American Society of Mechanical Engineers (ASME) Boiler Code, Section III, Division 1, Article III-2000 (see Reference 19). The stress limits are based on the minimum specified 0.2 percent offset yield strength and the ultimate strength of the unirradiated cladding.

For application with M5, the approved unirradiated yield strengths of M5 are also used in the criteria. For the cladding, however, the hoop yield strength, derived from bi-axial tests, is used instead of the axial tensile strength. FANP stated the limiting stresses are in the circumferential direction (the maximum shear stress is the circumferential minus the small radial stress) so use of the higher circumferential clad yield strength, as compared to the usual axial tensile strength limit, is acceptable. In addition for cladding, the allowed beginning of life membrane stress in compression is extended to the hoop yield stress rather than two-thirds of this stress. These criteria are as approved in Reference 2.

3.3.1.2 Strain (RODEX2-2A)

This criterion is revised for applications with M5 clad in accordance with the approved Reference 2 to a limit of 1 percent for rod burnups to 62 GWd/MTU.

The methodology to evaluate the cladding strain uses the RODEX2-2A code (References 13 and 10) to simulate the most demanding fuel rod power histories with the most conservative combination of pellet and cladding properties in order to maximize end-of-life cladding strain and to maximize cladding ramp strains. This methodology is unchanged. The incorporation of M5 cladding properties into the RODEX2-2A code is discussed in Section 3.1 of this SE.

3.3.1.3 Strain Fatigue (RAMPEX)

The cladding fatigue evaluation is based on the cyclic stress amplitudes calculated for the specified number of duty cycles during the irradiation life using the O'Donnell and Langer (Reference 20) fatigue design curve. This criterion, approved in the existing methodology in accordance with Reference 4, was shown to be conservative for M5 in accordance with Reference 2 based on M5 cyclic strain fatigue tests.

The same M5 clad properties as incorporated in RODEX2-2A are incorporated in RODEX2 to assure that the clad and pellet-starting condition for ramps is properly determined for M5 clad rods.

The clad creep correlation as benchmarked for RODEX2 in accordance with Sections 3.1.1.1 and 3.1.1.2 of this SE, is also incorporated in RAMPEX. The clad corrosion, hydrogen pickup, and the irradiation component of axial elongation are not incorporated, as these are not necessary for evaluating ramp stresses.

For the stress-strain curve in RAMPEX, the cold worked stress relieved (CWSR) Zircaloy-4 property is retained for simplicity and for conservatism in the evaluation of the fatigue stresses. The stresses during ramps are evaluated against the fatigue usage criteria using the O'Donnell and Langer design curve, which is described in terms of stress amplitude. FANP stated that the use of the higher CWSR material yield strength assures that plastic strain during the ramp is minimized resulting in the maximum calculated stresses. According to FANP, these stresses are conservatively determined and are on the same basis as used in the fatigue design criterion of O'Donnell and Langer.

Based on the discussion above, the staff agrees with FANP's strain fatigue (RAMPEX) model and finds it acceptable.

3.3.1.4 Fretting Wear

FANP's design basis for fretting corrosion and wear specifies that fuel rod failures due to fretting shall not occur (Section 3.3.3 of Reference 4). Fretting wear depends chiefly on spacer grid and rod retention system design features and on the hydraulic environment in which the fuel rod operates. Based on its similar composition, as well as the results of post-irradiation fuel rod inspections, FANP expects M5 cladding and grid spacers to exhibit the same fretting wear behavior as Zircaloy-4.

The NRC evaluation of fretting wear in the M5 TR (Reference 2) concluded that a change in cladding material should not have a significant impact on fretting wear. The fretting criterion defined in the M5 TR and in the FANP Group M generic criteria TR (Reference 4) are consistent and both are in accordance with SRP Section 4.2. The method of confirmation that fretting will not occur is similar between Reference 2 and Reference 4 in that both rely on a 1000-hour fretting test and in-reactor experience. Fretting tests have been performed for each of the assembly designs manufactured by FANP.

Based on the staff's conclusion in Reference 2 that a change in cladding material has no significant impact on fretting wear, the staff finds the fretting tests performed by FANP acceptable.

3.3.1.5 Oxidation, Hvdriding, and Crud

FANP stated that for M5 cladding, the approved rod oxide thickness measurements, corrosion equation, and the 100-micron criteria remain valid for this application. According to FANP, M5 cladding is expected to meet this corrosion criterion by a wide margin, up to a burnup of 62 MWd/kgU.

3.3.1.6 Rod Bow

Differential expansion between fuel rods and guide tubes, as well as lateral thermal and flux gradients, can lead to lateral creep rod bow in the spans between spacer grids. This lateral creep bow changes rod-rod gaps in the span between spacer grids and may affect the peaking and local heat transfer. The FANP design basis for fuel rod bowing specifies that lateral displacement of the fuel rods shall be sufficiently small that it does not affect thermal margins (Section 3.3.5 of Reference 4).

FANP stated that the use of M5 material in rods and guide tubes is expected to have little, or possibly a beneficial, effect on the occurrence of rod bow. Rod bow is in part, due to the forces on the rod resulting from differential expansion between the rod and guide tubes. The overall lower growth of the M5 material should reduce differential growth and the potential for bow induced by axial forces. The staff agrees that the growth characteristics of M5 will not have a detrimental effect on rod-bow.

3.3.1.7 Axial Growth

The FANP generic methodology (Reference 4) uses bounding empirical models to compute the irradiation growth of the clad and fuel assemblies. The bounding models are established by a 95/95 statistical evaluation of the growth measurements. The resulting dimensional changes are then compared with the available clearances, including the component and core tolerance accumulations. The 95/95 bounding models may be re-correlated as additional data becomes available. These re-correlations need not be submitted if the new correlation is within one standard deviation of the referenced correlation.

3.3.1.7.1 *Fuel Rod Growth*

The clearance between the upper and lower tie plate shall be designed to accommodate the maximum differential fuel rod and fuel assembly growth to the design burnup. The upper bound fuel rod growth is used in conjunction with the lower bound assembly growth and the manufacturing tolerances that would result in the minimum fabricated clearance. An M5 fuel rod elongation correlation is available from the approved Reference 2. It is updated with additional irradiated fuel measurements and is shown in Figure 6.1 of Reference 1.

3.3.1.7.2 *Fuel Assembly Growth*

The fuel assembly growth shall not exceed the minimum space between the upper and lower core plates in the reactor in the cold condition. The cold condition is limiting since the thermal expansion coefficient of the stainless steel core barrel is greater than the coefficient of expansion of Zircaloy-4 or M5 guide tubes.

The M5 assembly growth data and bounds are plotted in Figure 6.2 of Reference 1. FANP stated that the data show variability between different assembly configurations. According to FANP, such variation has been seen for Zircaloy-4 structure FANP assemblies where different growth correlations have been developed for different assembly types. FANP stated that the M5 assembly design bounds are conservative for reasons discussed in Section 6.1.7 of Reference 1.

The staff agrees that the M5 assembly design bounds are conservative for reasons discussed in Section 6.1.7 of Reference 1. Based on these conservatisms, the staff finds fuel assembly growth acceptable.

3.3.1.8 Rod Internal Pressure

When the fuel rod internal pressure exceeds system pressure, the pellet-cladding gap has to remain closed if it is already closed, or it should not tend to open for steady or increasing power conditions. Outward circumferential creep, that may cause an increase in pellet-to-cladding gap, must be prevented since it would lead to higher fuel temperature and higher fission gas release. The maximum internal pressure is also limited to protect embrittlement of the cladding caused by hydride reorientation during cool down and depressurization conditions.

The incorporation of M5 cladding properties into RODEX2-2A code is discussed in Section 3.1 of this SE. The existing methods for evaluating the margin to the fuel rod pressure limit with the RODEX2-2A code will be retained.

FANP stated that M5 cladding has a lower corrosion rate than Zircaloy-4 clad and a lower hydrogen pickup fraction, which results in lower hydrogen concentrations in M5 cladding than in Zircaloy-4 clad for the same reactor duty. According to FANP, the pressure stresses in M5 clad will be the same as those in Zircaloy-4 cladding for the same operational conditions. FANP stated that because the same design pressure criterion is chosen for the M5 clad fuel rods, the limiting hydride reorientation behavior will be bounded by that for Zircaloy-4. FANP concludes the design criterion pressure limit used for Zircaloy-4 is therefore conservative and applicable for M5 cladding.

Based on the lower corrosion rate of M5 cladding than that for of Zircaloy-4 and lower hydrogen pickup fraction, the staff agrees the design criterion pressure limit used for Zircaloy-4 is conservative and acceptable for M5 cladding.

3.3.1.9 Assembly Liftoff

The FANP design criterion for assembly liftoff specifies that the assembly shall not levitate from hydraulic loads (Section 3.3.8 of Reference 4). Therefore, for normal operation and AOOs, the submerged fuel assembly weight and holddown force must be greater than the upward hydraulic loads.

FANP stated that M5 cladding and structural material has a small effect due to the change in material density affecting the weight and the change in coefficient of thermal expansion and assembly growth affecting the bundle length and thus the holddown spring force. The density and thermal expansion properties are approved by Reference 2. The length projections are revised with additional data in Section 6.1.7.2 of Reference 1. According to FANP, these changes will be implemented in the liftoff calculations.

3.3.1.10 Fuel Assembly Handling

The assembly design must withstand all normal axial loads from shipping and fuel handling operations without permanent deformation. FANP uses either a stress analysis or testing to demonstrate compliance. The analysis or test uses an axial load of 2.5 times the static fuel assembly weight. At this load, the fuel assembly structural components must not show any yielding. For these evaluations, the M5 density will be used to determine M5 component weights; the M5 tensile strength will be used to determine strength margins.

3.3.1.11 Control Rod Reactivity

FANP's design basis for the fuel assembly specifies that the technical specification shutdown margin (SDM) will be maintained (Section 5.2 of Reference 4). Specifically, the assemblies and core must be designed to remain subcritical with the highest reactivity worth control rod fully withdrawn and the remaining control rods fully inserted. SDM is calculated and demonstrated at the beginning of the cycle (as a minimum) for each reactor. FANP stated thatstandard approved design methods are used to ensure that adequate limits are placed on control rod worth.

FANP stated that the change in alloy content from approximately 1.4 percent tin in the Zircaloy-4 to 1.0 percent Nb in the M5 will tend to slightly increase the neutron absorption cross-section of the M5 compared to Zircaloy-4. According to FANP, this change in cross section has a negligible impact on control rod worth. The staff agrees that the small increase in neutron absorption cross-section of M5 compared to Zircaloy-4 will not have a detrimental effect on control rod reactivity.

3.3.2 <u>Fuel Rod Failure</u>

3.3.2.1 Hydriding (Internal)

FANP reduces the potential for hydrogen absorption on the inside of the cladding by eliminating potential sources of moisture during fuel rod fabrication, including the careful control of fuel pellet moisture content. By controlling the moisture content of the fuel pellets, the fabrication limit for total hydrogen inside the fuel rod is maintained at a minimal level (Section 3.2.1 of Reference 4).

The absorption of hydrogen by fuel rod cladding can result in cladding failure due to reduced ductility and the formation of hydride platelets. To verify that acceptably low levels of hydrogen are being maintained, a statistical sample of fabricated pellets is selected for analysis, and the hydrogen content is measured and compared to the established limit. According to FANP no significant level of fuel failures due to internal hydriding have been experienced, confirming that the testing and sampling processes permit adequate control of moisture within the fuel rods.

FANP stated that they will continue the current practice for controlling internal hydrogen concentration; internal hydriding experience with M5 cladding is expected to be the same as for Zircaloy-4 cladding.

3.3.2.2 Cladding Collapse

The FANP cladding creep collapse criterion is designed to prevent the formation of significant axial gaps in the fuel pellet column due to pellet densification (Section 3.2.2 of Reference 4). The opening of axial gaps in the pellet column creates the potential for cladding to collapse (flatten) into the gap, where the large local strains resulting from cladding collapse could be sufficient to cause clad failure. Thus, the cladding creep collapse criterion is established to preclude cladding collapse during the design lives of fuel rods and burnable absorber rods.

As described in Section 3.1 of this SE, the M5 properties are incorporated in the RODEX2-2A code that calculate radial creepdown and also provide pressure and temperature information to the COLAPX code which then predicts the development of creep ovality. The RODEX2-2A benchmarking was used to determine the M5 creep coefficients to use with the existing COLAPX creep model. FANP stated that the existing COLAPX elastic modulus was not changed from that of Zircaloy for the applicable temperature range. According to FANP, the slight modulus increase for M5 (about 1 percent) will have a negligible effect on the calculated creep ovality. The staff concurs.

The COLAPX code does not model the entire fuel rod, and thus is not suitable for direct M5 creep benchmarking. A RODEX2 code version, which contains the COLAPX creep model and has the whole fuel rod modeling capability, was used in the COLAPX M5 creep model benchmarking.

Figures 6.3 and 6.4 of Reference 1 display the benchmarking results. Both figures show that with the best-fit creep coefficients, the COLAPX creep model properly predicts the M5 creep data. The approved procedure using RODEX2-2A and COLAPX is therefore used with M5 properties incorporated in RODEX2-2A and with the creep projections for RODEX2-2A and COLAPX benchmarked to M5 rod data.

Based on the benchmark results, the staff finds the cladding creep collapse model acceptable.

3.3.2.3 Overheating of Cladding

The design basis to preclude fuel rod cladding overheating specifies that there must be at least 95 percent probability at a 95 percent confidence level that any fuel rod in the core does not experience departure from nucleate boiling (DNB) during steady-state operation and AOOs (Section 3.2.3 of Reference 4).

3.3.2.3.1 *Effect of M5 Cladding on DNB Phenomena*

Overheating of the cladding occurs when there is a sharp reduction in the surface heat transfer coefficient caused by the formation of an insulating vapor layer on the cladding surface. This phenomenon is commonly referred to as DNB. The parameters that dominate the heat flux at which DNB occurs include: (1) the mechanical design of the fuel assembly, in particular, the spacer grid which is designed to strip the vapor layer from the cladding surface; and (2) the fluid conditions, such as mass flux, pressure, and quality. FANP stated that the cladding material and its thermal conductivity and heat capacity have no significant effect on the surface heat transfer coefficient and surface heat flux at which DNB occurs. When a vapor layer exists on the cladding surface, the fuel rod is not conduction limited, and the rod heat flux is dominated by the surface heat transfer coefficient. Therefore, according to FANP, there is no significant effect of either M5 cladding or Zircaloy-4 cladding on DNB phenomena. The staff agrees the effect of M5 cladding on DNB phenomena is not significant.

3.3.2.3.2 *Effect of M5 Cladding on Departure from Nucleate Boiling Ratio (DNBR) Criterion*

Fuel cladding integrity is maintained by ensuring that the minimum DNBR remains above the 95/95 DNB correlation limit for a given fuel design. The 95/95 DNB correlation limit is derived from DNB test data. As indicated by FANP above, neither M5 nor Zircaloy-4 cladding has a significant effect on DNB phenomena. Thus, Inconel clad heater rods in DNB tests typically simulate fuel assemblies. Therefore, according to FANP, the use of M5 cladding will have no effect on the DNB data or the DNBR criterion (95/95 DNB correlation limit). The staff agrees the effect of M5 cladding on DNBR criterion is not significant.

3.3.2.4 Overheating of Fuel Pellets

The design criterion for overheating of fuel pellets specifies that the centerline temperature of the fuel pellets must remain below the pellet melting temperature during normal operation and AOOs (Section 3.2.4 of Reference 4).

The centerline-melting criterion was established to assure that axial or radial relocation of molten fuel would neither allow molten fuel to come into contact with the cladding nor produce local hot spots. For normal operation and AOOs, centerline-melting is not permitted. In calculations of radiological dose for the case of postulated accidents, all rods that experience centerline-melting are assumed to fail. FANP stated that their assumption that centerline-melting results in fuel failure is conservative.

The margin to centerline-melting is calculated with the RODEX2-2A code in which predictions of fuel temperature are dependent on linear heat rate, the fuel properties, the state of the pellet-clad gap, and the thermal conductivity of the clad. As described in Section 4.0 of Reference 1, the properties for M5 cladding have been incorporated into the RODEX2-2A code. FANP stated that the existing methods for evaluating the margin to fuel melting with the RODEX2-2A code will use the applicable M5 properties. The staff agrees that the existing methods for evaluating the margin to fuel melting with the RODEX2-2A code using the applicable M5 properties are acceptable.

3.3.2.5 PCI

The SRP does not contain explicit criteria to address PCI; however, it does present three related criteria:

(1) The uniform strain of the cladding should not exceed 1 percent. In this context, uniform strain (elastic and inelastic) is defined as transient-induced deformation with gage lengths corresponding to cladding dimensions.

(2) Fuel melting should be avoided. The large volume increase associated with melting may cause a pellet with a molten center to exert a stress on the cladding.

(3) Clad fatigue usage shall be limited. Cyclic loading associated with relatively large changes in power can cause cumulative damage, which may eventually lead to fatigue failure.

These criteria are unaffected by the change from Zircaloy-4 to M5. Incorporation of M5 properties in the methodology to address these criteria is described in Sections 6.1.2, 6.1.3, and 6.2.4 of Reference 1.

3.3.2.6 Cladding Rupture

The approved M5 cladding rupture model (Reference 2) is incorporated in the S-RELAP5 methodology as described in Section 5.1.14 of Reference 15.

3.3.2.7 Mechanical Fracturing

Accident evaluation of the fuel assembly is performed in accordance with the previously approved methodology (References 21 and 22). Determination of assembly loads is typically performed with a dynamic analysis. For this analysis, the change in properties from Zircaloy-4 to M5 must be considered. The properties, which affect dynamic response, are the material density and modulus of elasticity.

For new dynamic evaluations, the approved M5 properties (Sections 4.1.8 and 5.1.6 of Reference 1) for the applicable M5 components will be used for both determining dynamic response and strength margins. The approved (Reference 2) tensile yield strength of the M5 cladding and guide tubes (Section 6.1.1 of Reference 1) will be used in this evaluation. M5 spacer grids, if used, will be evaluated by strength testing of the specific M5 grid design as described in the methodology (References 21 and 22).

FANP limits the combined stresses from postulated accidents to the stress limits given in ASME Code Section III, Appendix F for faulted conditions (Section 3.2.7 of Reference 4).

3.4 S-RELAP5 Based 10 CFR Appendix K PWR SBLOCA Methodology

The addition of approved M5 cladding properties and models to the two computer codes used in the approved S-RELAP5 based 10 CFR Appendix K PWR SBLOCA methodology (RODEX2-2A and S-RELAP5) (Reference 5) is straightforward and was described in Sections 4.0 and 5.0 of Reference 1. FANP stated that the methodology for performing SBLOCA calculations that was approved in Reference 5 is unchanged except to add the properties specific to M5 cladding. However, some M5 properties that were required for SBLOCA analyses were either not available in the approved documents, required a range of applicability that extended outside the approved range, or required a new correlation for model-specific usage. These properties include creep, growth, thermal expansion, emissivity, elastic modulus, and rod rupture flow blockage. Where applicable, the modifications to the approved M5 properties have been discussed and justified in Sections 3.1.1 and 3.2.1 of this SE.

FANP stated that changing cladding type to a material similar to Zircaloy, such as M5, will have an insignificant impact on important criteria for SBLOCA analyses. According to FANP, the results from the sample problem discussed in Section 7.4 of Reference 1, confirm this expectation. The analysis shows that little variation in calculated peak cladding temperature (PCT) or oxidation occurs when M5 cladding is substituted for Zircaloy cladding in an SBLOCA calculation. The staff agrees that M5 cladding will have an insignificant impact on important criteria for SBLOCA analyses.

3.4.1 Methodology Summary

The approved methodology for evaluation of SBLOCA transient response for both CE- and Westinghouse-designed PWRs is described in Reference 5. The use of M5 cladding affects the fuel rod model used in this methodology. The purpose of the SBLOCA analysis is to demonstrate that the criteria stated in 10 CFR 50.46(b) are met under the conditions of a SBLOCA. These criteria are as follows:

1. The calculated maximum fuel element cladding temperature shall not exceed 2200°F.

2. The calculated local fuel rod cladding oxidation shall nowhere exceed 17 percent of the total cladding thickness before oxidation.

3. The calculated total amount of fuel element cladding, which reacts chemically with water or steam, shall not exceed 1 percent of the Zircaloy within the heated length of the core.

4. The cladding temperature transient shall be terminated at a time when the core geometry is still amenable to cooling.

5. The core temperature shall be reduced and decay heat shall be removed for an extended period as required by the long-lived radioactivity remaining in the core.

S-RELAP5 is the principal computer code used for analysis of the SBLOCA event. Before the analysis can be performed, S-RELAP5 requires initial fuel rod conditions. The rod conditions are determined by RODEX2-2A where the fuel burnup is calculated to the desired burnup level, usually end of cycle conditions. The RODEX2-2A results at the desired burnup are transferred to S-RELAP5. A steady-state calculation using S-RELAP5 is made that initializes the system model to plant operating conditions. After assuring the steady-state calculation is representative of the plant operating conditions, the SBLOCA transient is performed. In addition to calculating the overall system thermal-hydraulic response, S-RELAP5 also concurrently calculates the hot rod temperature transient using the hot rod input including RODEX2-2A fuel models and the NUREG-0630 swelling and rupture models for analyses with Zircaloy cladding. The approved swelling and rupture models for M5 (Reference 2) have now been incorporated into S-RELAP5 for analyses with M5 cladding.

After calculations and analyses have been made to determine the limiting single failure, a break spectrum is analyzed by making several calculations with varying break sizes. From this calculation set, the results are examined to determine the break size having the greatest PCT or maximum oxidation present. The calculation having the greatest PCT or maximum amount of cladding oxidized in the break spectrum is the limiting SBLOCA break yielding the reportable PCT, and becomes the analysis of record. The results of this analysis are also compared to the criteria in 10 CFR 50.46(b) for reporting purposes.

3.4.2 Summary of Clad-Related Models in the SBLOCA Methodology

3.4.2.1 RODEX2-2A

The RODEX2-2A code is used to perform the fuel burnup calculation before initiating the S-RELAP5 calculation. The cladding related models implemented in RODEX2-2A for M5 cladding are described in Section 3.1.1 of this SE. Cladding surface roughness is another cladding related parameter that is specified in user input.

3.4.2.2 S-RELAP5

The S-RELAP5 code is used to perform the transient SBLOCA calculation. It performs the system thermal-hydraulic calculation as well as the hot rod heat-up, rupture, and deformation calculations. The cladding related models implemented in S-RELAP5 for M5 cladding are described in Section 3.2.1 of this SE. Cladding surface roughness is another cladding related parameter that is specified in user input.

3.4.3 M5 Properties and Correlations Implemented in SBLOCA Models

3.4.3.1 Cladding Creep Correlation

M5 cladding creep for SBLOCA calculations is implemented in the rod burnup calculation as discussed in Section 4.1.1 of Reference 1 in the RODEX2-2A code. Note that cladding creep is a burnup-dependent parameter. The duration of an S-RELAP5 SBLOCA calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding creep is not calculated in the S-RELAP5 code.

3.4.3.2 Cladding Free Growth

M5 cladding free growth for SBLOCA calculations is implemented in the rod burnup calculation as discussed in Sections 4.1.2 and 4.3 of Reference 1 in the RODEX2-2A code. Note that cladding free growth is a burnup-dependent parameter. The duration of an S-RELAP5 SBLOCA calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding free growth is not calculated in the S-RELAP5 code.

3.4.3.3 Cladding Thermal Conductivity

M5 cladding thermal conductivity for SBLOCA calculations is implemented as discussed in Sections 4.1.3 and 5.1.3 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.4 Cladding Oxide Thermal Conductivity

M5 cladding oxide thermal conductivity for SBLOCA calculations is implemented as discussed in Sections 4.1.4 and 5.1.4 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.5 Cladding Specific Heat

M5 cladding specific heat for SBLOCA calculations is implemented in the transient calculation as discussed in Section 5.1.5 of Reference 1 in the S-RELAP5 code. Note that cladding heat capacity is not used in the RODEX2-2A code. RODEX2-2A calculations assume quasi-steady thermal conditions for each burnup interval so specific heat is not required.

3.4.3.6 Cladding Density

M5 cladding density for SBLOCA calculations is implemented in the transient calculation as discussed in Section 5.1.6 of Reference 1 in the S-RELAP5 code. Note that cladding density is not used in the RODEX2-2A code. Density would be multiplied by the specific heat to provide a volumetric heat capacity. However, RODEX2-2A calculations assume quasi-steady thermal conditions for each burnup interval so heat capacity and density are not required.

3.4.3.7 Cladding Thermal Expansion

M5 cladding thermal expansion for SBLOCA calculations is implemented as discussed in Sections 4.1.7 and 5.1.7 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.8 Cladding Modulus of Elasticity

M5 cladding Young's modulus for SBLOCA calculations is implemented as discussed in Sections 4.1.8 and 5.1.8 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.9 Poisson's Ratio

M5 cladding Poisson's ratio for SBLOCA calculations is implemented as discussed in Sections 4.1.9 and 5.1.9 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.10 Cladding Emissivity

M5 cladding emissivity for SBLOCA calculations is implemented as discussed in Sections 4.1.10 and 5.1.10 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.4.3.11 Cladding Corrosion

M5 cladding corrosion for SBLOCA calculations is implemented in the burnup calculation as discussed in Section 4.1.11 of Reference 1 in the RODEX2-2A code. Low temperature cladding corrosion is not calculated in S-RELAP5.

3.4.3.12 Cladding Hydrogen Pickup

M5 cladding hydrogen pickup for SBLOCA calculations is implemented in the burnup calculation in the RODEX2-2A code as discussed in Section 4.1.12 of Reference 1. Cladding hydrogen pickup is not calculated in S-RELAP5.

3.4.3.13 High Temperature M5/Steam Reaction Kinetics

Metal-water reaction kinetics for SBLOCA calculations is implemented in the transient calculation as discussed in Section 5.1.13 of Reference 1 in the SRELAP5 code. The RODEX2-2A calculations are performed at normal reactor operating conditions. The temperature of the cladding during normal operating conditions is not high enough for significant metal-water reaction to take place. Therefore, only low-temperature cladding corrosion models are used to determine cladding oxidation in the RODEX2-2A code.

3.4.3.14 Cladding Surface Roughness

Surface roughness is an input parameter that is more closely associated with the cladding manufacturing process than the cladding material type. Currently, manufactured surface roughness is input to the RODEX2-2A code for cladding internal surface roughness. This practice will continue with M5 cladding. FANP stated that it is not anticipated that M5 rod external surface roughness will differ substantially from Zircaloy cladding. According to FANP, the same external surface roughness for the thermal-hydraulic calculation performed by S-RELAP5 will be used for M5 as is currently used for Zircaloy cladding.

3.4.3.15 Cladding Swelling and Rupture/Blockage

M5 cladding swelling and rupture modeling for SBLOCA calculations is implemented during the transient calculation in the S-RELAP5 code as discussed in Section 5.1.14 of Reference 1. The RODEX2-2A code is used to calculate burnup-dependent fuel behavior at normal reactor operating conditions. FANP stated that under these conditions, swelling and rupture/blockage will not occur and, therefore, no swelling and rupture/blockage model is implemented in the RODEX2-2A code.

3.5 Non-LOCA Methodology

The FANP non-LOCA methodology is composed of three approved methods: SRP Chapter 15 Non-LOCA Transient Methodology for Pressurized Water Reactors, Statistical Setpoint/Transient Methodology for Westinghouse-Type Reactors, and Statistical Setpoint/Transient Methodology for CE-Type Reactors (References 6 through 8). A discussion is presented below about the issues related to cladding type that are important to each methodology. The implementation of M5 models applicable to the non-LOCA methodologies in the affected computer codes (RODEX2-2A and S-RELAP5) is then described. The description is followed by a sample problem for statistical setpoint/transient methodologies with M5 cladding.

3.5.1 Methodology Summary

3.5.1.1 SRP Chapter 15 Non-LOCA Transient Methodology

The approved methodology for evaluation of SRP Chapter 15 non-LOCA transients for both CE- and Westinghouse-designed PWRs is described in Reference 6. The use of M5 cladding affects the fuel rod model used in this methodology. Reference 6 explicitly addresses the fuel rod model that is to be applied using S-RELAP5. Two options are available for the fuel rod model. The XCOBRA-IIIC code (Reference 23) is also used in the approved SRP Chapter 15 non-LOCA transient methodology but does not perform material property or deformation calculations for the cladding or fuel.

The approved methodology (Reference 6) does not require revision to support M5 cladding. The methodology prescribes the conditions under which an evaluation must be repeated due to changes in fuel design. The specific changes that cause reevaluation are (page 3-3 of Reference 6):

- Free volume to fuel ratio
- Cladding type (creepdown behavior)
- Porosity
- Change in certain RODEX2 properties (pellet resintering, pellet cracking, porosity)
- Cycle exposure
- Change in fuel rod code to code other than RODEX2

The introduction of M5 cladding changes the cladding type. Therefore, consistent with the approved Reference 6 methodology, the first application involving M5 cladding requires an evaluation for use with M5 cladding.

The qualification of the RODEX2-2A model is described separately in Section 4.0 of Reference 1. Since the approved methodology specifically addresses the possibility for differing cladding types, a sample problem is not required in this report to quantify the impact of the change from Zircaloy to M5 cladding.

3.5.1.2 Statistical Setpoint/Transient Methodology for Westinghouse-Type Reactors

The statistical setpoint/transient methodology as applied to Westinghouse-type PWRs is described in Reference 7. It is used to calculate trip setpoints and to verify trip systems and limiting conditions of operation. FANP stated that the methodology is not affected by the use of M5 cladding material. Most of the phenomena evaluated in the methodology are associated with cladding surface effects. The evaluation of the fuel rod power associated with centerline-melting represents the only fuel rod internal effect that participates in the analysis. According to FANP, this evaluation is performed with RODEX2-2A and is functionally identical for the two cladding materials. The qualification of the RODEX2-2A code is described separately in Section 3.1.1 of this SE.

3.5.1.3 Statistical Setpoint/Transient Methodology for CE-Type Reactors

The statistical setpoint/transient methodology as applied to CE-type PWRs is described in Reference 8. It is used for analyzing limiting conditions of operation, limiting safety system settings, and transients for CE PWRs. The methodology is not affected by the use of M5 cladding material. Most of the phenomena evaluated in the methodology are associated with cladding surface effects. The evaluation of the fuel rod power associated with centerline-melting represents the only fuel rod internal effect that participates in the analysis. FANP stated that this evaluation is performed with RODEX2-2A and is functionally identical for the two cladding materials. The qualification of the RODEX2-2A code is described separately in Section 3.1.1 of this SE.

3.5.2 Summary of Clad Related Models in Non-LOCA Methodology

3.5.2.1 RODEX2-2A

The RODEX2-2A code is used to determine appropriate clad- and fuel burnup-dependent fuel rod parameters for input to the S-RELAP5 calculation for SRP Chapter 15 non-LOCA transient analyses. The statistical setpoint/transient methodologies use RODEX2-2A to perform the fuel burnup and centerline fuel temperature calculations to determine the fuel melt limit. The cladding related models implemented in RODEX2-2A for M5 cladding are described in Section 3.1.1 of this SE. Cladding surface roughness is another cladding related parameter that is specified in user input.

3.5.2.2 S-RELAP5

The S-RELAP5 code is used to perform SRP Chapter 15 non-LOCA transient calculations. It performs the system thermal-hydraulic calculation including the average core and limiting hot spot (hot rod) heat transfer.

While current SRP Chapter 15 non-LOCA transient calculations use another cladding model, the SE in Reference 6 approved the use of the RODEX2 models incorporated in the S-RELAP5 code for SRP Chapter 15 non-LOCA transient calculations if desired. The cladding related models implemented in S-RELAP5 for M5 cladding that are relevant to SRP Chapter 15 non-LOCA transients if the second option is used are described in Section 3.2.1 of this SE. Cladding surface roughness is another cladding related parameter that is specified in user input.

3.5.3 M5 Properties and Correlations Implemented in Non-LOCA Models

3.5.3.1 Cladding Creep Correlation

M5 cladding creep for non-LOCA calculations is implemented in the rod burnup calculation as discussed in Section 4.1.1 of Reference 1 in the RODEX2-2A code. Note that cladding creep is a burnup-dependent parameter. The duration of an S-RELAP5 SRP Chapter 15 non-LOCA transient calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding creep is not calculated in the S-RELAP5 code.

3.5.3.2 Cladding Free Growth

M5 cladding free growth for non-LOCA calculations is implemented in the rod burnup calculation in the RODEX2-2A code as discussed in Sections 4.1.2 and 4.3 of Reference 1. Note that cladding free growth is a burnup-dependent parameter. The duration of an S-RELAP5 SRP Chapter 15 non-LOCA transient calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, cladding free growth is not calculated in the S-RELAP5 code.

3.5.3.3 Cladding Thermal Conductivity

M5 cladding thermal conductivity for non-LOCA calculations is implemented in the RODEX2-2A and S-RELAP5 codes as discussed in Sections 4.1.3 and 5.1.3 of Reference 1.

3.5.3.4 Cladding Oxide Thermal Conductivity

M5 cladding oxide thermal conductivity for non-LOCA calculations is implemented in the RODEX2-2A and S-RELAP5 codes as discussed in Sections 4.1.4 and 5.1.4 of Reference 1.

3.5.3.5 Cladding Specific Heat

M5 cladding specific heat for non-LOCA calculations is implemented in the S-RELAP5 code for SRP Chapter 15 non-LOCA transient calculations as discussed in Section 5.1.5 of Reference 1. Note that cladding heat capacity is not used in the RODEX2-2A code and, therefore, is not used in the statistical setpoint/transient methodology. RODEX2-2A calculations assume quasi-steady thermal conditions for each burnup interval so specific heat is not required.

3.5.3.6 Cladding Density

M5 cladding density for non-LOCA calculations is implemented in the S-RELAP5 code for SRP Chapter 15 non-LOCA transient calculations as discussed in Section 5.1.6 of Reference 1. Note that cladding density is not used in the RODEX2-2A code and, therefore, is not used in the statistical setpoint/transient methodology. Density would be multiplied by the specific heat to provide a volumetric heat capacity. However, RODEX2-2A calculations assume quasi-steady thermal conditions for each burnup interval so heat capacity and density are not required.

3.5.3.7 Cladding Thermal Expansion

M5 cladding thermal expansion for non-LOCA calculations is implemented as discussed in Sections 4.1.7 and 5.1.7 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.5.3.8 Cladding Modulus of Elasticity

M5 cladding Young's modulus for non-LOCA calculations is implemented as discussed in Sections 4.1.8 and 5.1.8 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.5.3.9 Poisson's Ratio

M5 cladding Poisson's ratio for non-LOCA calculations is implemented as discussed in Sections 4.1.9 and 5.1.9 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.5.3.10 Cladding Emissivity

M5 cladding emissivity for non-LOCA calculations is implemented as discussed in Sections 4.1.10 and 5.1.10 of Reference 1 in the RODEX2-2A and S-RELAP5 codes, respectively.

3.5.3.11 Cladding Corrosion

M5 cladding corrosion for non-LOCA calculations is implemented in the burnup calculation in the RODEX2-2A code as discussed in Section 4.1.11 of Reference 1. The duration of an S-RELAP5 SRP Chapter 15 non-LOCA transient calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, low temperature cladding corrosion is not calculated in the S-RELAP5 code.

3.5.3.12 Cladding Hydrogen Pick-up

M5 cladding hydrogen pick-up for non-LOCA calculations is implemented in the burnup calculation in the RODEX2-2A code as discussed in Section 4.1.12 of Reference 1. The duration of an S-RELAP5 SRP Chapter 15 non-LOCA transient calculation is sufficiently short to hold burnup-dependent parameters constant. Therefore, low temperature cladding hydrogen pick-up is not calculated in the S-RELAP5 code.

3.5.3.13 Cladding Surface Roughness

FANP stated that surface roughness is an input parameter that is more closely associated with the cladding manufacturing process than the cladding material type. Currently the manufactured surface roughness is input to the RODEX2-2A code for cladding internal surface roughness. According to FANP, it is not anticipated that M5 rod external surface roughness will differ substantially from Zircaloy cladding and therefore, the same external surface roughness for the thermal-hydraulic calculation performed by SRELAP5 will be used for M5 as is currently used for Zircaloy cladding (5.0x10-6 ft for typical drawn tubing, page A-23 of Reference 22).

4.0 CONDITIONS

The proposed changes to FANP's approved methods are approved based on the following conditions, which FANP has agreed upon via Reference 24:

1. The corrosion limit, as predicted by the best-estimate model will remain below 100 microns for all locations of the fuel.

2. All of the conditions listed in the SEs for all FANP methodologies used for M5 fuel analysis will continue to be met, except that the use of M5 cladding in addition to Zircaloy-4 cladding is now approved.

3. All FANP methodologies will be used only within the range for which M5 data was acceptable and for which the verifications discussed in BAW-10240(P) or Reference 2 was performed.

4. The burnup limit for this approval is 62 GWd/MTU.

5.0 CONCLUSIONS

The staff finds that the proposed changes to incorporate M5 properties in FANP-approved methods are in compliance with 10 CFR 50.46 and 10 CFR Part 50 Appendix K. Therefore, on the basis of the above review and justification, the staff concludes that BAW-10240(P), "Incorporation of M5 Properties in FANP Approved Methods," is acceptable.

6.0 REFERENCES

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4. EMF-92-116(P)(A) Revision 0, "Generic Mechanical Design Criteria for PWR Fuel Designs," Siemens Power Corporation, February 1999.

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11. Letter from NRC to James Mallay (Framatome), Request for Additional Information re: BAW-10240-P, "Incorporation of M5 Properties in Framatome ANP Approved Methods," (TAC No. MB7553), July 16, 2003.

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19. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Article III-2000, Design Stress Intensity Values for Class 1 Components, 1977.

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21. XN-NF-696(P)(A), ENC's Solution to the NRC Sample Problems-PWR Fuel Assemblies Mechanical Response to Seismic and LOCA Events, Exxon Nuclear Company, April 1986.

22. XN-76-47(P)(A), Combined Seismic-LOCA Mechanical Evaluation for Exxon Nuclear 15x15 Reload Fuel for Westinghouse PWR's, Exxon Nuclear Company, January 1982.

23. XN-75-21 (P)(A) Revision 2, XCOBRA-IIIC: A Computer Code to Determine the Distribution of Coolant During Steady State and Transient Core Operation, Exxon Nuclear Company, January 1986.

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